STATUS OF SCSS: SPRING-8 COMPACT SASE SOURCE PROJECT

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Abstract

The SPring-8 Compact SASE Source (SCSS) is a high peak-brilliance soft X-ray free electron laser project. It is the linac-based FEL dedicated machine. Combination of the high-gradient C-band accelerator and the in-vacuum short-period undulator enable to fit SCSS within 100 m machine length. The project aims to generate first light in 2005 at VUV region, and ultimately 3.6 nm in water-window. This paper reports current R&D status on SCSS.

1 SCSS CONCEPT

The X-ray FEL lasers based on the SASE usually need a large-scale accelerator and a long undulator, as the result, such machine becomes extremely high cost. This is the reason why people design the X-ray FEL as a parasitic facility attached to an existing electron accelerator: LCLS assumes to use the Two-mile Linac at SLAC, or as an integrated facility into a future large-scale machine such as TESLA linear collider. Therefore, a chance to have X-ray FEL facility is quite limited and can be regionally localized.

However, if we can make construction cost of the X-ray FEL much lower than existing synchrotron light-sources based on the storage ring, each country or region can possess their own machines, and it will accelerate research activities in material science and biology. To do this, the most important point is to make the machine size compact, thus the building cost will be lowered, as well as the machine itself becomes inexpensive.

In the SCSS project, the following three key technologies realize the compact machine as Fig. 1.

(1) In-vacuum undulator enables the undulator period shorter, thus the beam energy becomes lower, as a result smaller the accelerator size. It also contributes to shorten the FEL gain length.

(2) High gradient C-band accelerator, in which accelerating gradient as high as 40 MV/m enables the main linac length being only 30 m to reach 1 GeV.

(3) Low emittance beam injector based on thermionic single crystal CeB_6 cathode makes the FEL gain higher, and saturation length shorter.

2. SCSS MACHINE

2.1 Machine Layout

Figure 2 shows the machine layout at the final stage of SCSS project, whose parameter is summarized in Table-1. SCSS consists of the low emittance electron injector, the C-band main linac, the bunch compressors and the undulator section for FEL interaction.

In order to saturate FEL at shortest wavelength in SCSS: λ_x =3.6 nm within 20 m, we need a short bunch of 0.5 psec.$_{FWHM}$, peak current of 2 kA, and 1 nC charge.

Note that, in this paper, we describe the bunch length in FWHM value rather than rms vale (σ_z). This is because in our system the longitudinal current profile has rather flat shape than Gaussian shape.

2.2 Electron Injector

In the SCSS project, we chose a high-voltage pulse-gun with thermionic-cathode, instead of RF-Gun. As kwon in SASE-FEL theory, the quality of "internal" structure of bunched beam dominates FEL performance, that is, the slice emittance and slice energy spread directly affect the FEL gain. We believe a single crystal LaB_6 or CeB_6 cathode will provide high performance beam with uniform density, well laminar with no turbulence, low emittance.

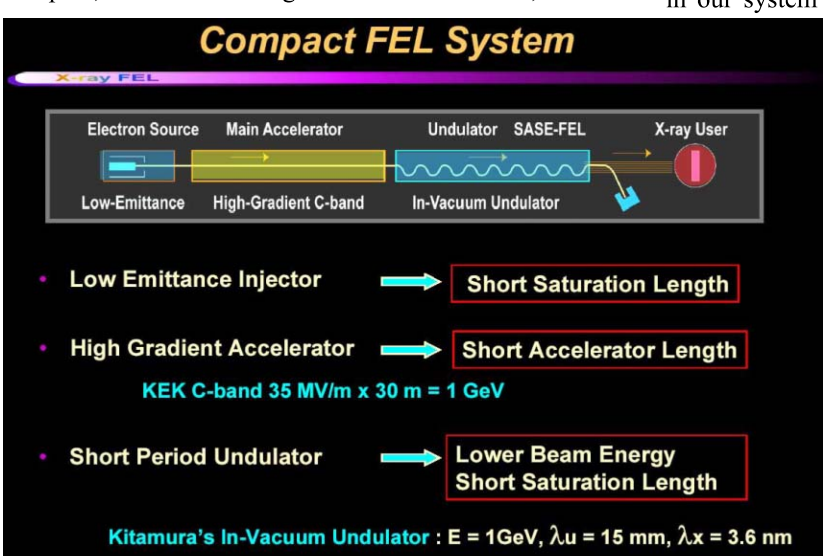


Fig.1 What makes SCSS compact?

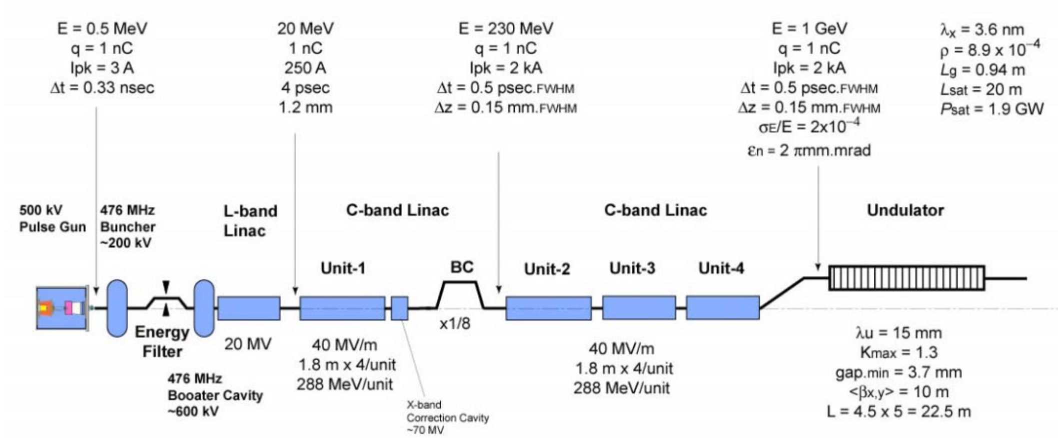


Fig.2 SCSS beam line layout at final stage (beam energy 1GeV, radiation wavelength 4 nm).

In the HV pulse gun, 3 Amp. beam with 300 nsec flat-top pulse will be pulled out from a single-crystal CeB_6 cathode of 3 mm. The R&D issue on this design is (1) development of reliable 500 kV pulsed power supply, (2) reliable heating mechanism for the cathode (nominal operation temperature is 1450 deg-C). We schedule the high-voltage test, and high temperature test in 2002.

Right after the gun, a beam chopper will be prepared, which cuts out the rising and falling parts of the pulse, and forms a 2 nsec pulse beam. The 476 MHz pre-buncher adopts energy modulation of 400 kV peak-to-peak. The following energy filter cut the energy tail (top and bottom). After drifting 800 mm beam pipe, due to the velocity difference, electrons form a short bunch at the centre energy.

The L-band accelerator captures the bunch, and accelerates to 20 MeV. Since the bunch length at the entrance is still long, we chose L-band frequency, this is the lowest frequency band where a high-peak power klystron is commercially available and also the fabrication of the accelerating structure is relatively easy.

The parameter optimisation work of the injector is reported at this conference [2].

Table-1 SCSS design parameter at final stage: 1 GeV. Note that the bunch length is denoted by FWHM value.

bunch charge	Q	1	nC
normalized emittance	$\varepsilon_{nx,y}$	2	πmm.mrad
final electron energy	E	1	GeV
final rms energy spread	σ_δ	0.02	%
final FWHM bunch length	Δz	0.15	mm
	Δt	0.5	psec
peak current	I_{pk}	2	kA
undulator period	λ_u	15	mm
radiation wavelength	λ_x	3.6	nm
minimum gap	g	3.7	mm
maximum K-parameter	K	1.3	
undulator unit length	L_1	4.5	m
total undulator length		22.5	m
beta function	β	10	m
FEL parameter	ρ	8.9	x 10^{-4}
gain length	L_g	0.94	m
saturation length	L_{sat}	20	m
saturation power	P_{sat}	2.0	GW

2.3 C-band Main Linac [3]

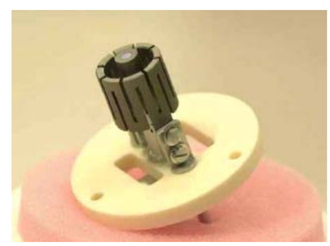


Fig.3. CeB_6 single crystal cathode with graphite heter.

We use four units of the C-band accelerator system. Each unit is capable of accelerating beam by 288 MeV, and total four units provide 1 GeV beam. The C-band (5712 MHz) accelerator technology has been developed at KEK Japan as the main linac of the future 500 GeV e+e- Linear Collider project. Table-2 summarises results of the phase-I R&D on C-band during 1996~2000. The SCSS will provide a best string test of the main linac system for the Linear Collider project.

2.4 Bunch Compressor

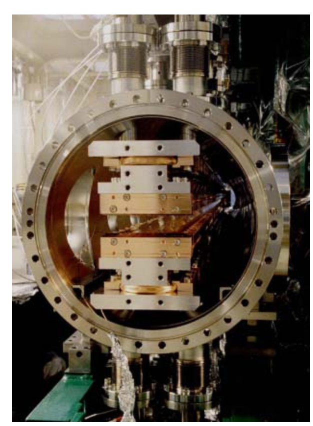


Fig.4 The 37 m in-vacuum undulator installed in the 8 GeV storage ring at SPring-8 in 2001. We use same design for SCSS project.

In the chicane type magnetic bunch compressor, the bunch is compressed to 0.5 $psec._{FWHM}$. Since the coherent synchrotron radiation (CSR) effect dominates to break transverse emittance, we need careful design. Recently a new finding was made at DESY SLAC collaboration: the CSR amplifies micron-scale density fluctuation on the incoming bunch, it is now called “CSR instability”[4]. To avoid CSR instability and emittance break-up, we are trying to shorten the bunch length in the injector by proper modulation voltage, and reducing the compression factor at the downstream bunch compressor.

2.6 Undulator

The undulator consists of five segment of 4.5 m long in-vacuum undulator, and the total active length is 22.5 m. One big benefit of in vacuum undulator is “variable gap”. For the machine commissioning, and tuning, we open up the gap, then close down the gap for FEL operation. It is very safe, and operational ease. One big issue is “phase matching” and “alignment” between undulator segments. After detail study, we confirmed that SASE-FEL does not fully require perfect overlapping of optical wave to the electron beam, that is, in practice we do not need precise beam alignment and phase matching, which has been believed before [5].

3 REFERENCES

[1] T. Shintake, “SPring-8 Compact SASE Source”, SPIE2001, San Diego, USA, June 2001.

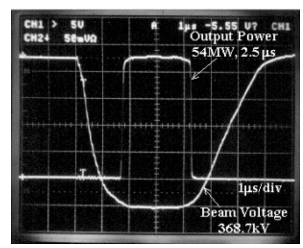
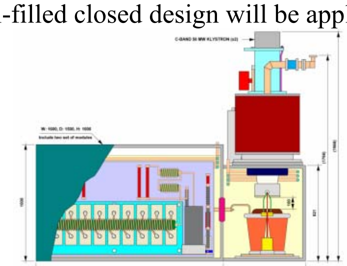
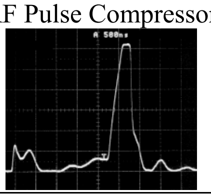
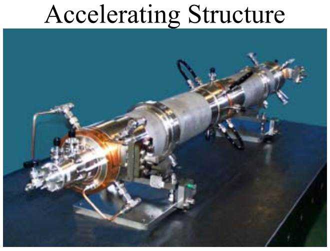
[2] Y. J. Kim, et al., “Beam Parameter Optimisation for the SPring-8 Compact SASE Source”, in this conference.

[3] http://c-band.kek.jp

[4] “CSR Workshop 2002”, January 14-18, 2002 at DESY-Zeuthen (Berlin, GERMANY). http://www.desy.de/csr/

[5] T. Tanaka, H. Kitamura and T. Shintake, “Misalignment effects of segmented undulator in self-amplified spontaneous emission”, Phys. Rev. ST Accel. Beams 5, 040701 (2002)

Table-1 Phase-I R&D summary on C-band RF-system and application to SCSS.

Items	Phase-I R&D Target / Achieved Results	SCSS Application (Phase-II)
Klystron 	Output 50 MW、Efficiency >45% Pulse width >2.5 µsec Pulse repetition 100 pps Focusing Power < 5 kW	Refine design details for the mass-production and reducing cost. PPM-klystron is an option.
	All of No.1, 2, 3 tubes achieved 50 MW output, pulse width 2.5 µsec and 50 pps. No. 3 tube showed 47% power efficiency. Focusing power 4.6kW. Life test No.2, 3 > 5000 hours.	 Example of output power.
Pulse Modulator Supply 	350 kV、2.5 µsec pulse generation, power efficiency >50%	Oil-filled closed design will be applied. 
	Smart Modulator, No. 1 Inverter HV power supply was firstly used in klystron modulator. Operation for klystron life-test was very successful. Power efficiency >52.4%	
RF Pulse Compressor 	Power gain >3.5、 Power efficiency >70%	Temperature stabilized design will be employed. Invar body with copper plating will provide better than one tenth phase-sensitivity on the temperature variation. High power test is scheduled in 2001.
	Cold Model Test (1997) Power Gain 3.25, Efficiency 65% Not yet performed the high-power test.	
Accelerating Structure 	Multi-bunch 1.6 nC, 80 bunch Acceleration gradient> 35 MV/m	Refine design details. Optimization for mass-production. Lowering cost. The multi-bunch option in SCSS will provide high average brightness.
	ASSET test at SLAC demonstrated damping performance of the choke-mode cavity.	
	Resolution ~ 25 nm (FFTB test) Position accuracy < 10 µm	